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THIRD PARTIAL REPORT ON RESEARCH ON  
PROPULSION OF ROCKET PROJECTILES

by

L. A. Skinner

January 1938

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U.S. ARMY ABERDEEN RESEARCH AND DEVELOPMENT CENTER  
BALLISTIC RESEARCH LABORATORIES  
ABERDEEN PROVING GROUND, MARYLAND

Report No. 95

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THIRD PARTIAL REPORT ON RESEARCH ON PROPULSION OF ROCKET  
PROJECTILES.

Research Project R.Z. - 101.  
Authority A.P.G. 121.2/12196.

ABSTRACT

On the basis of previous work several types of rocket projectiles were made to fit the 3" Trench Mortar. While this size is believed to be considerably small for the type of projectile it was chosen because of the availability of mortars and material from which the projectiles could be made up fairly easily at minimum cost.

Double base stick powder was used as the driving charge and a method of packing, size of orifice, and method of igniting worked out which gave much more consistent and satisfactory performance than in the past. Projectiles were somewhat heavier than necessary and rather crude, being made primarily from salvaged material and within the limitation of the tools available. No attempt at accuracy firing was made due to insufficient number of projectiles and to the necessity of working out many details before this step would be logical. No attempts were made to reach maximum range. Mortar pressure was held down to a maximum of about 4000 p.s.i. and projectiles having a driving charge were fired in comparison with similar projectiles having no driving charge (the propelling charge in the mortar and angle of elevation being the same) to get the increase in range of the rocket projectile over the similar ordinary projectile.

The average increase in range on those rocket projectiles which functioned fairly well was about 75%. Maximum range on a 15 lb. rocket projectile was about 2200 yds. as compared to about 850 yds. for a similar projectile without driving charge. (Increase 158%). Bursting charge capacity of this shell was 1.52 lb. T.N.T.; driving charge 205 grams stick powder.

## PREVIOUS REPORTS

First Partial Report on Research on Rocket Propulsion of Projectiles, O.P. 5191 A.P.G., Md., April 7, 1933. O.O. 475.75/859; A.P.G. 475.71/2. Book 72.

An Investigation of Erosion in Orifices Caused by Powder Gases at High Temperature and Velocity. Watertown Arsenal, May 7, 1934. Report No. 731/4.

Research on Rocket Propulsion of Projectiles. Research Project RZ-101, A.P.G. May 31, 1935. Report No. 7. A.P.G. 121.2/12196.

Second Partial Report on Research on Rocket Propulsion of Projectiles. Research Project RZ-101. A.P.G. 121.2/12196. July 29, 1936.

### Purpose:

The purpose of this investigation has been to determine if it is practicable to add a force produced by a rocket charge to a projectile in flight which will:

(1) permit a reduction in weight and complication of the gun firing it and still give a range and effectiveness which compare with similar weight conventional shells,

(2) or an increased range without seriously decreasing the effectiveness or increasing the weight of the projectile.

### Scope and Limitations:

The information obtained from this phase of the investigation has shown that a driving charge can be fired after the projectile is in flight and will give an increase in range. The driving charge used burned comparatively slowly with ejection velocity of the gases probably much lower than the maximum that might be obtained without developing appreciably higher driving chamber pressure. It is most probable that the ejection velocity was further reduced by step dulling of the ejection nozzle which causes eddies in the gases. It is believed that a smooth properly proportioned ejection cone would materially increase the effectiveness of the driving charge, even though the rate of burning of the charge was not increased.

The projectile itself was of poor form for good stability and low air resistance as demonstrated by the short ranges obtained by fairly high mortar pressure when firing the projectile as a conventional finned shell. Also the weight of the projectile was unduly high due to the character of the makeshift materials used and the effort to keep expense at a minimum; the object being to demonstrate a principle rather than to perfect its application.

#### DESCRIPTION OF MATERIEL

##### Mortar:

The mortar was a standard 3" T.M. Mk. I mounted in the usual way on a bipod and resting on a Mark II base plate. The mortar closing cap and firing pin were removed and a cap having a short section of 1903 .30 Cal. rifle barrel and receiver mounted in it, was screwed onto the base of the mortar. This permitted firing the mortar by a lanyard attached to the trigger of the rifle rather than in the usual way of dropping the shell down the tube and firing by striking the propelling cartridge primer on a firing pin. Functioning was quite satisfactory.

##### Primer:

The primer was made by loading a .30 Cal. blank with 4 grams of Grade A-4 black powder, the E.C. powder having first been removed.

##### Propelling charge:

Flake powder as furnished in capsules for the 81 mm T.M. was used, however difficulty having been experienced in getting proper ignition with the powder in the capsules it was removed and made up in silk bags of 300 and 800 grains respectively. The silk used was cut from the parachute of an old airplane parachute flare. Increment rings of ballastite of 110 grains each as furnished for the 3" T.M. were used to augment the 800-grain bag when more than this amount was desired. Ignition of the propelling charge was satisfactory after repacking the latter as noted above.

##### Driving charge:

The driving charge powder was a special stick powder made by Picatinny Arsenal under P.A. Ex. Order 357-50, Procurement Authority Ord 7291 Expt. Lot 1970, June 29, 1937.

The composition is as follows:

Nitrocellulose (13.15% N)	54.0%
Nitroglycerine	43.0%
Vaseline	3.0%
Diphenylamine (added)	0.65%

#### Dry Measurements.

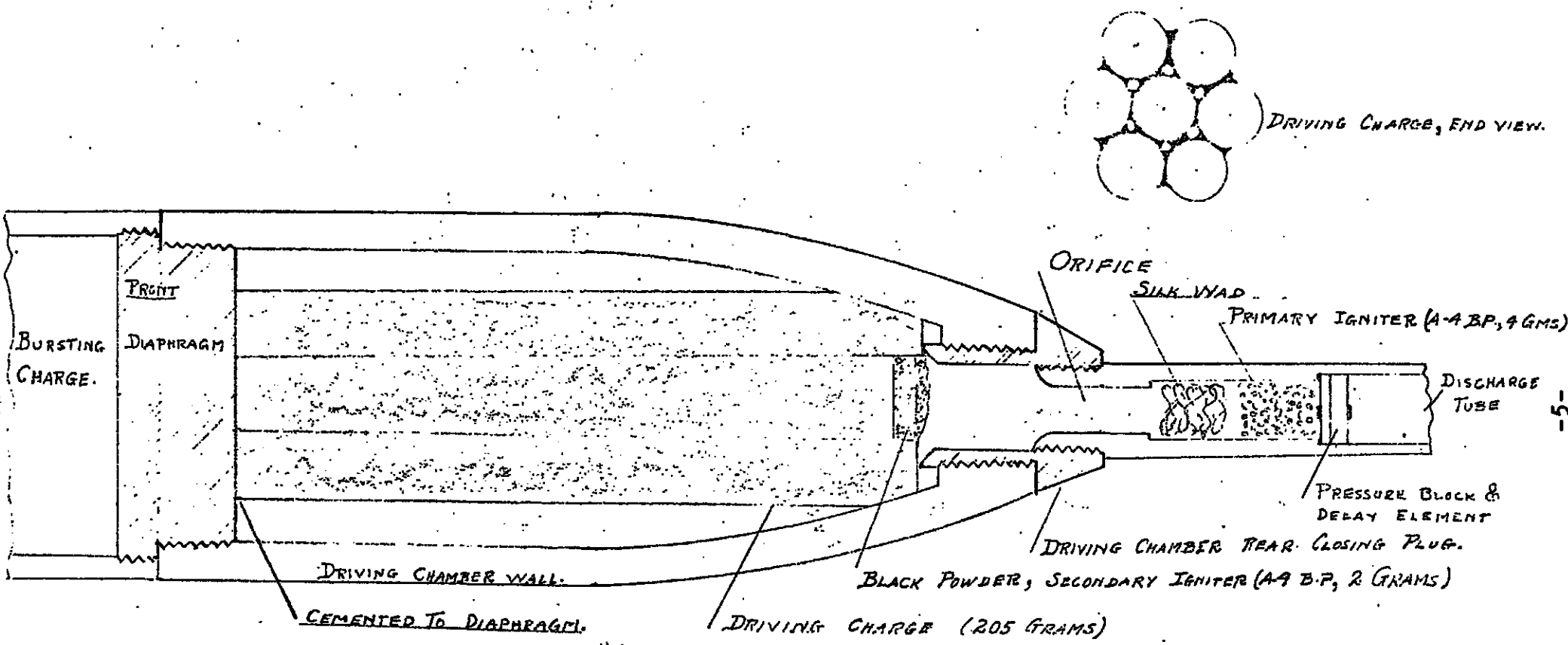
Grain form	Core
Diameter	0.625
Length	4.0 inches
Unperforated.	

There was space in the driving charge chamber (except as noted under latest type projectile described under type IV) for 7 sticks of powder. It was found if the sticks were simply placed in the chamber almost invariably one of them became wedged in the orifice on firing and caused the driving charge to burst the chamber due to closing of the escape port. To overcome this seven sticks were cemented with colloided F.N.H. powder (acetone being the suspending medium) into a cluster, six sticks being arranged around a center stick. This cluster was then cemented to the front closing plug or diaphragm of the driving charge chamber with a gasket cement and further held in place against set back by the lip of the rocket chamber rear closing plug bearing on the six peripheral sticks of powder and holding them firmly against the rocket chamber front closing plug.

It is realized that the use of this colloid as a cement probably had some effect on the burning characteristics of the powder, but again attention is invited to the fact that the purpose has been to demonstrate a principle rather than to perfect its application. Work had not yet progressed to the stage where serious attempts at uniformity or maximum efficiency were made; satisfactory functioning of the various elements in the desired order being at the time the greatest interest.

While this method of packing the charge served to eliminate the blocking of the orifice, another method was tried with Type IV projectiles, which will be described, and which appears to offer promise of better performance and which does away with the use of any adhesive.

See Figure 1.



LOADING 81 M.M. ROCKET TYPES I, II & III.  
 NOT TO SCALE

FIG. 1.

*LA Skinner*  
 July 19, 1937.

### Igniting charges:

Reference to Figure 1 will show the location of the primary and secondary igniting charges. The primary igniting charge, consisting of four grams of Grade A-4 Black Powder is held in place in the discharge tube and against the delay element by a silk wad. The secondary igniting charge of 2 grams of the same grade of black powder is placed in a shallow well in the center of the cluster of driving charge sticks and held in place by a patch of silk cemented across the end of the charge.

The sequence on firing is as follows:

1. The primer is fired by pulling the trigger on the mortar firing mechanism.
2. The primer flame ignites the propelling charge.
3. The propelling charge forces the projectile out of the tube and ignites the powder train of the delay element.
4. The delay element powder train burns through its set delay and ignites the primary igniting charge.
5. The primary igniting charge ignites the secondary igniting charge which assists in the ignition of the driving charge.

This sequence of events has functioned successfully and is the only one of several arrangements that was satisfactory.

### The Pressure Block-Delay Element:

The delay-pressure block element was first developed and used in April 1935 in connection with this project in the modification of several Coston Ship Signal Rockets (Discussed in Report No. 7, May 31, 1935).

It was not used, having become more or less lost in the many details and problems arising, in rocket projectiles until this series of shell was made. The accomplishment of a reasonable rate of driving charge burning was not realized with a high potential powder until the introduction of this element into the system. It appears now that the key to the successful burning of high potential powder in a rocket projectile fired by powder pressure from a tube is the protection of the driving charge from the pressure generated by the burning propelling charge.

It had been noted in previous firings that when a small propelling charge was used and the rocket discharge tube was left open, that fair ignition and burning of the driving charge could be obtained. However when the propelling charge was in-

creased and a higher mortar pressure developed, the driving charge would burst its container very close to the muzzle of the gun. Realizing that pressure increases the rate of burning of this kind of powder a pressure block was made which served the two following purposes:

1. Protection of the driving charge from the pressure and heat of the burning propelling charge.

2. Incorporation of a selective delay for igniting the driving charge at some selected time after the projectile had left the gun tube.

Increased effect of the rocket propelling force is obtained if the driving charge is fired while the projectile is moving at or near the highest velocity given it by the mortar, yet it should be far enough away so that the high velocity ejected gases do not spray around the gun. This is the reason for the delay. Just where the most protected point on the trajectory of igniting this charge is, has not yet been definitely determined.

Figure 2 shows a sketch of the pressure block-delay element as made up for these projectiles. The loading of the time train was done in a home-made die, regular 21 sec. fuze powder being used. No attempt at especially good uniformity was made. When properly mounted in the discharge tube to prevent leakage of gas past the body, they functioned satisfactorily, if not uniformly. At longest setting burning time was about  $3/4$  second. The body of the element is blown out of the tube on ignition of the driving charge.

Figure 1 shows the positioning of this element in the discharge tube.



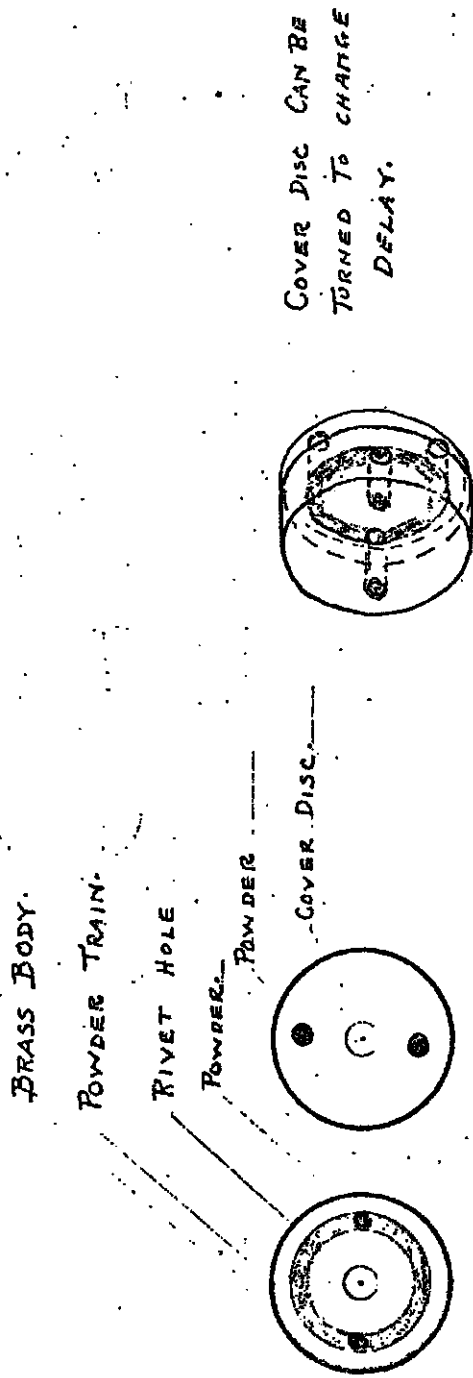
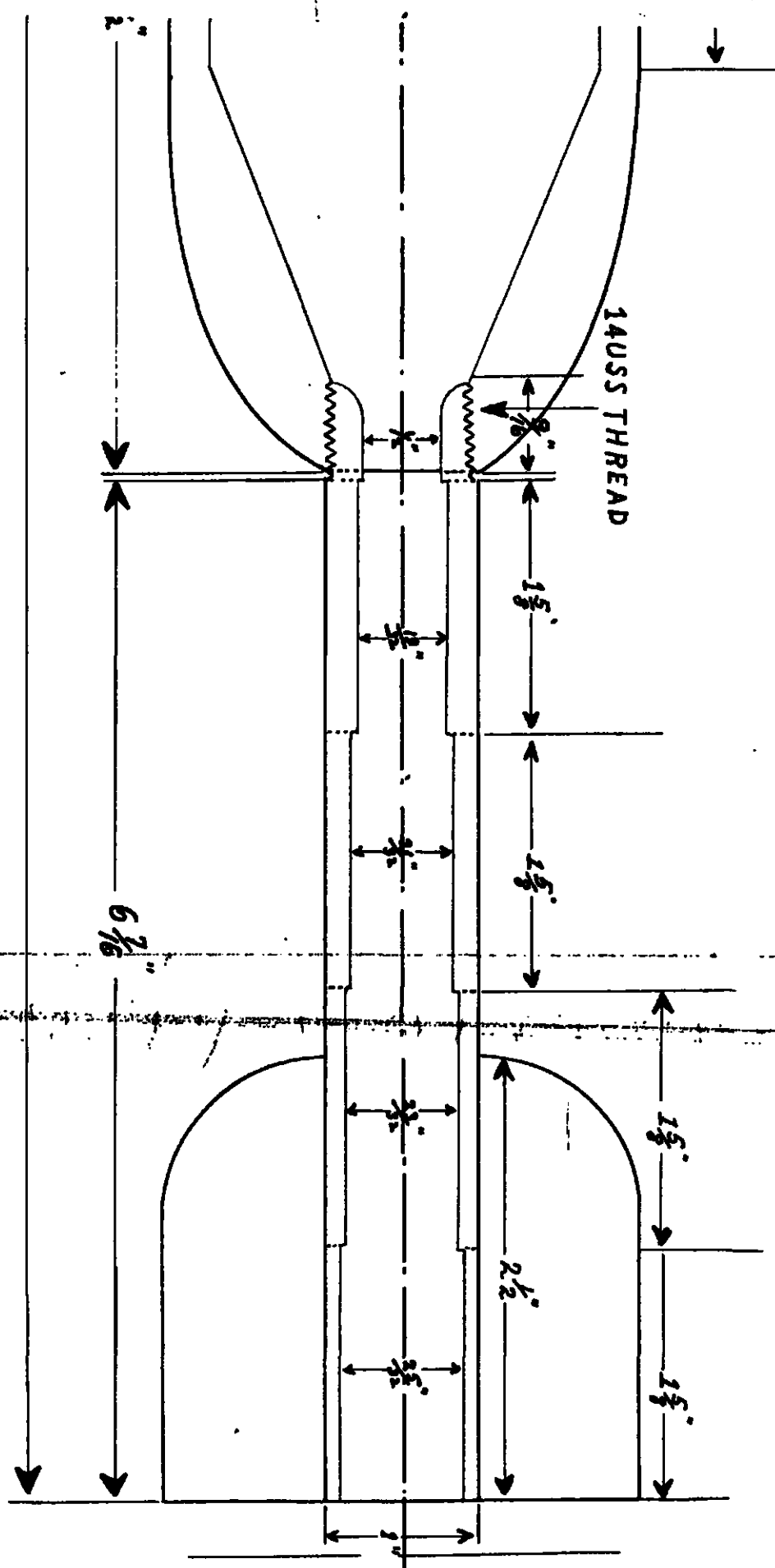


FIG. 2.

PRESSURE-BLOCK AND DELAY ELEMENT.  
NOT TO SCALE

L.A. Sanner  
August 8, 1937





### The Projectile - Assembled. (Figure 3)

The projectile was a composite of salvaged material available at Aberdeen Proving Ground. Reference to Figure 3 will clarify its make-up. In types I, II and III (see Photographs 35954, 36195, 36278) the construction is the same from the diaphragm back except for the double fin in the latter two but differs from type IV which will be described separately.

The tail group: in the first three types was made up of the diaphragm, the driving charge chamber, the adapter, the discharge tube and the fins.

The diaphragm was made of mild steel (W.D. 1040), its construction being obvious in the drawing. When assembled into the projectile the threads were coated with a gasket compound to minimize the possibility of gas leaks.

The driving charge chamber was made from recovered 3" A.A. H.E. Shell M-42. The bases were cut off and the nose end remaining turned down internally to a thickness of about 1/4".

The adapter as used was cut down from a MK. III adapter.

The discharge tube was made from new stock, seamless 1" steel tubing (O.D. 1", I.D. 1/2") and was step drilled as shown. While it is desirable that the interior of this tube should be conical (probably a cone of an overall angle of 8° - 10° being near the proper flare) it was not so made due to the lack of tools to do it economically. Step drilling was resorted to to approximate this shape.

The fins were taken from recovered 81 mm M43 practice shell. They were bored out so as to be a snug fit over the outside of the discharge tube and were welded in place.

The nose group varies in types I, II and III. In type I it was made from the body of 3" T.M. MK I projectile to which was welded a nose section left over from a range firing program of 3.3" experimental projectiles, the overall nose length being 8 1/2". This type yawed rather badly in flight. Its bursting charge capacity was 1.63 pounds of T.N.T. and total projectile weight empty 10 lbs. 10 ozs.

Type II nose group was made up the same way as type I except the bursting chamber was longer, the nose heavier and of different profile. Capacity of bursting chamber was 2.2 lbs. of T.N.T. and the length 10 1/2". Total projectile weight empty 13 lbs. 2 ozs. The increase in length was made in an attempt to move the center of gravity ahead and the second fin added in an

attempt to move the center of pressure to the rear to increase stability. This was not realized however and this type was more unstable than the first.

Type III nose group had a bursting chamber of the same material as I and II but was 5 1/2" long and had welded to the forward end, the front closing plug taken from 3" T.M. MK. I projectile. Capacity was 1.2 lbs. of T.N.T. and a MK VI 3" T.M. fuze was used. Due to the ranges being reached at this stage it was impossible to spot the landing of the shell without a bursting charge, so this group was loaded with 12 oz. of black powder. Stability of this type was good. Its total weight empty was 10 lbs. 10 ozs.

Type IV projectile differed considerably from types I, II and III. (See Figure 4 and Photograph 36363). This projectile was made by modifying an 81 mm T.M. high capacity shell T-9 which had previously been fired and recovered. The rear end of the shell was cut off as shown in Photograph No. 36363 and a cylinder, which is the driving charge chamber welded into the opening and braced as shown. The discharge tube was 5 1/2" on this shell as against 7" in the first three types and carried one fin as shown. The orifice was the same as in the others, namely 3/8". This shell had a total weight empty of 9 lbs. 10 ozs. and had a bursting charge capacity of approximately 3 lbs. of T.N.T. A driving charge of 147 grams was carried.

In this projectile no cement was used with the driving charge but it was arranged as shown in Figure 5. Three layers of powder were packed as shown (Figure 5), the finest granulation being nearest the orifice. From the limited number of static firings (four) made with this arrangement of powder in the driving charge there appeared to be no tendency of powder sticks to be blown into the orifice and no evidence of unburned pieces were found outside after firing and none remained in the chamber - indicating complete consumption of the charge.

Burning appeared to be quite rapid as judged from the report and the force developed by the driving charge considerably greater than produced by that used in types I, II and III. These comparative effects will be measured at a later date if time and circumstance permit.

Two rounds of this type were made and fired and in both cases prematured in the bore wrecking the mortar as shown in Photographs 36364 and 36476. Fragments of the shell found indicate that in the first round the bursting charge was ignited near the muzzle splitting the tube as shown. A large piece, probably the driving charge chamber and fins was seen to fly some 600 yards down the range although this could not be confirmed by locating this piece.

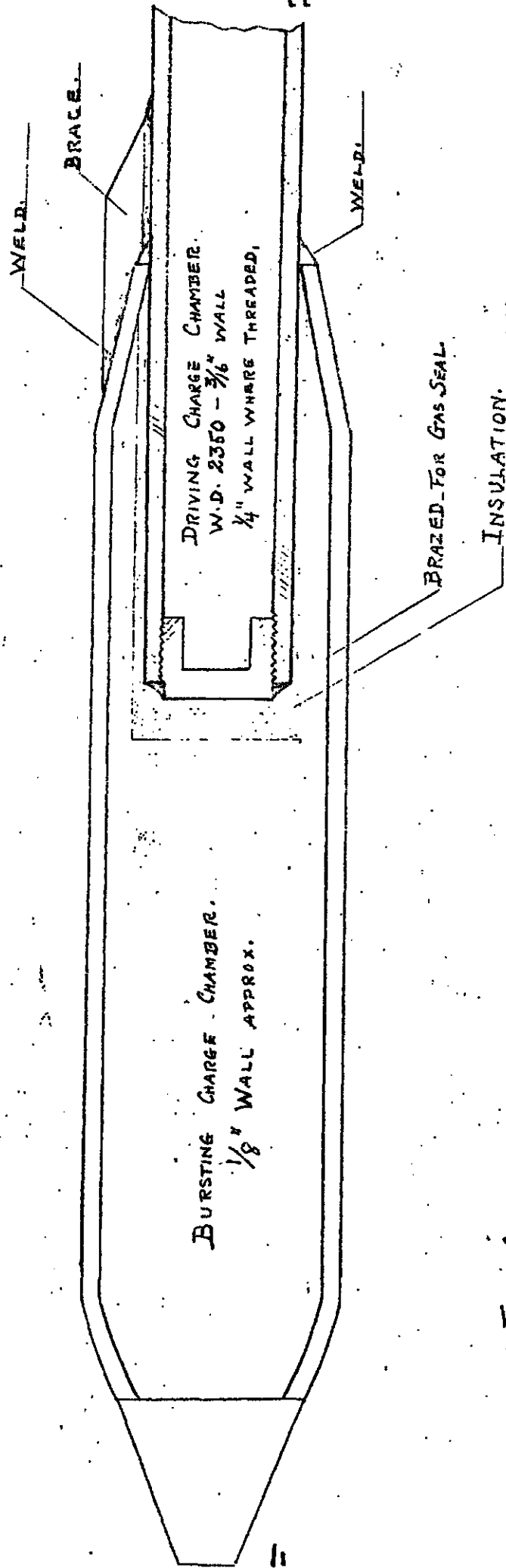


FIG. 4.

TYPE IV.

- NOT TO SCALE.

L.A. Spinner  
October 20, 1937.

In the second case, examination of fragments of the mortar tube very soon after the explosion showed it to have been of very coarse crystalline appearance and that probably it had been cracked in previous firings, since it showed rust deep in the fractured edges in some places. However fragments of the shell were also found, so there is some question as to whether the shell burst and burst the tube or the tube burst and wrecked the shell.

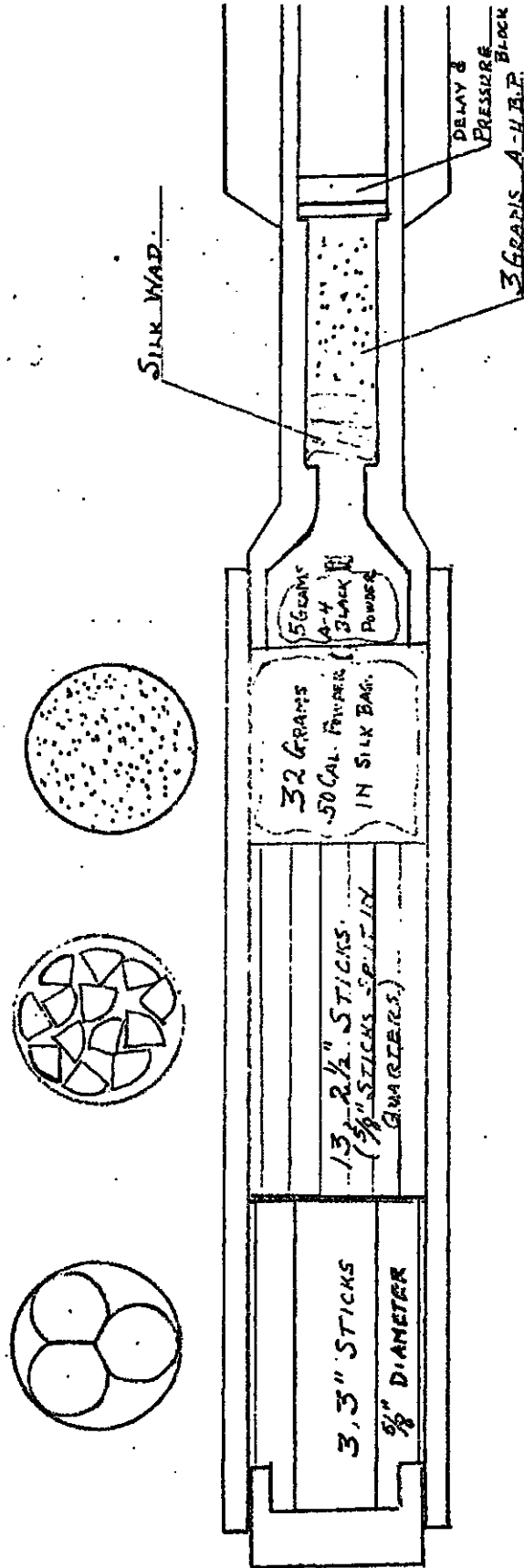


FIG. 5.

ARRANGEMENT OF DIVING CHARGE. TYPE IV.

NOT TO SCALE.

L. A. Skinner  
October 20, 1937.



### Method of Firing:

The mortar was set up in the usual manner except for the addition of the special firing mechanism and lanyard. The silk powder bag was loaded from the muzzle and the projectile dropped in on top of it, the primer was then inserted and the piece fired by lanyard from the shelter of a stockade. No attempt at uniformity in range was attempted due to the fact that information was being sought as to the effect of different lengths of delay in igniting the driving charge as well as different arrangements of the driving charge itself.

Before any live rockets were fired, a number without driving charge were fired with various weights of propelling charge to determine the range of the dead rocket and its behavior in flight in order that a comparison could be made when the same type of projectile was fired with a driving charge. Pressures were taken with each varying weight of propelling charge in a special tube fitted with a device for using revolver type crusher gauges.

Live rockets were fired with delay, ranging from that which started the burning of the driving charge practically at the muzzle to that which fired it after it had passed the peak of the trajectory. Longer ranges were obtained, other factors being as nearly equal as possible, when the driving charge was fired near the muzzle. Deflection effect of the driving charge was not separable from the effect of construction faults in the rockets themselves, but in no case were deflection errors extreme. One rocket, probably due to the orifice being off center, executed a maneuver similar to a "barrel roll" of an airplane, when the driving charge functioned at about the top of the trajectory and landed about  $10^{\circ}$  off the line of sight. All others remained within about  $5^{\circ}$  of the sight line, many landing very close to this line.

Table I shows the rounds fired and the results obtained.

The very limited number of rounds makes the range results of the firings of small value. The firings do show that the driving charge can be made to function in a projectile in flight and that it will add considerable range, but definitely how much and how consistently remains to be found out. Insomuch as much of the firing and much of the making of the projectile was done without assistance or with very little assistance, it was very difficult to keep strictly accurate account of observations and to locate projectiles on landing. The firing record leaves much to be desired.

TABLE I

Type	Weight Total		Drive Charge	Propelling Charge	Elev.	Approx. Place on Trajectory where Driving Charge Fired	Character of Flight	Orifice Diam.	Approx. Range (No Drive Charge) Same Shell Type	Range (with Drive Charge)	Defl.	Range % Increase
	lbs.	oz.	Wt. grams	Wt. grains	°							
I	16	0	150	600	45°	1 sec. after firing gun. 2 explosions heard. Shell could be heard in air for about 13 sec.	Not seen.	25/64"	480 yds.	Lost	Lost	
I	16	2	None	685	45°	None	Yawed badly.		580		40R	
I	16	2	None	1100	45°	None	Lost			Lost	Lost	
I	16	0	None	300	45°	None	Appreciable yaw.		280		0	
I	16	1	74	800	45°	Failed to ignite.	Appreciable yaw. Nose cap separated from shell at muzzle.	3/8"	600	580	10L	
I	15	0	None	800	45°	None	Nose removed before firing. Flight good.		650		80L	
I	13	6	None	800	65°	None	Bursting chamber wt. reduced. Flight good.		660		70L	
I	16	0	147	800	45°	Near top of trajectory.	Yawed badly.	3/8"	600	850	30R	41.6
II	15	0	None	300	45°	None	Yawed worse than Type I		390		1R	
II	13	3	None	300	45	None	Yawed badly.		375		20L	

Abandoned due to very poor flight characteristics.

TABLE I (Cont'd)

Type	Weight Total		Drive Charge	Propelling Charge	Elev.	Approx. Place on Trajectory where Driving Charge Fired	Character of Flight	Orifice Diam.	Approx. Range (No Drive Charge) Same Shell Type	Range (with Drive Charge)	Defl.	Range % Increase
	lbs.	oz.	grams	grains	o							
III	13	4	234	1320 (4400#/sq.in.)	450	Near muzzle. Drive charge fired twice.	Good	3/8"	1300 approx.	2100	90L	61.5
III	13	12	230	910	450	Near top of trajectory on upward leg. One loud rushing report made by driving charge.	Good	3/8"	850 approx.	2200-2400 Not found tho seen to land and burst.	120L Est.	158
III	13	8	230	910	450	Near top of trajectory on upward leg. Excellent firing of drive charge.	Good	3/8"	850 approx.	2200-2400 Est.	100L Est.	158
III	13	12	230	1230	450	About 1/2 distance from gun to top of trajectory. Excellent firing of drive charge.	Good	3/8"	1100 approx.	1960 Est.	10L	44
III	13	12	243	1130	450	Drive charge only partly burned.	Good	3/8"	1000 approx.	1650	20L	65
III	13	11	231	800	450	At top of trajectory. Excellent firing of drive charge.	Barrel-roll when drive charge fired.	3/8"	800 approx.	1450 observed from 3 positions.	200L	81
III	13	12	233	1020	450	Poor firing - 4 gentle reports, fired 400 yds. approx. from gun.	Good	3/8"	900 approx.	1600-1800 fell in woods. Observed from 3 positions.	On line 77 apparently.	

TABLE I (Cont'd)

Type	Weight Total		Drive Charge Wt.	Propelling Charge Wt.	Elev.	Approx. Place on Trajectory where Driving Charge Fired	Character of Flight	Orifice Diam.	Approx. Range (No Drive Charge) Same Shell Type	Range (with Drive Charge)	Range % Defl. Increase
	lbs.	oz.	grams	grains	°						
III	13	12	233	1240	45°	Fired at muzzle. Excellent firing of drive charge.	Good	3/8"	1100 approx.	1950 fell in water. Observed from 2 positions.	On line apparently.
IV	13	14	130	1240	45°	Premature in bore, burst mortar tube.					
IV	13	11	130	760	45	Burst mortar tube. Possible premature of projectile indicated. Examination of fragments indicates tube had been cracked in previous firings. Pressure with this propelling charge previously measured averaged 3300 lbs./sq.in.					

Approximate ranges with no driving charge are not exact is due to fact that these were fired without bursting charge and could not be located exactly in the tall brush where they fell. Due to the small number of rounds available (16, of which 5 blew up near the muzzle during the process of establishing a driving charge) the dead rounds were usually rockets which had been fired with a driving charge, were recovered and rebuilt but which had usually suffered some damage which was not repairable and which affected their flight to some degree.

### Discussion:

It is the opinion of the writer that the application of rocket propulsion to projectiles of the size herein reported is probably impractical. However the equipment and material available and the effort to spend as little money as possible led to the use of the 3" T.M. A minimum caliber of about 105 mm is indicated with a total weight of about 35 lbs. for the projectile.

To date the arrangement and amount of the driving charge has been entirely a matter of cut and try, however now that one which does work fairly well has been established, it is proposed to make a series of time-pressure curves using a Piezo-electric gauge and different arrangements of powder to get more exact data for future reference. The apparatus for this phase is completed and the results when obtained will be submitted as an additional partial report.

It should be emphasized that the results obtained so far are probably far from those obtainable with a properly designed projectile and driving charge powder. Due to the small diameter of the projectile used, the weight to volume relation was poor, the exterior finish and fins were rough, but most important, the orifice and discharge tube were a very poor makeshift and probably reduced the discharge gas velocity by a large percent. It is estimated that in a 105 mm shell weighing 35 pounds a driving charge of about 4 pounds could be carried, or in other words, an increase of about 2.5 times in total weight would give an increase in driving charge weight of about 9 times the present and still leave space for about 6 pounds of bursting charge. Furthermore the projector tube should be of such strength as to allow sufficient pressure to give the projectile a muzzle velocity of approximately 800 foot-seconds in order that a reasonable high velocity may obtain at the moment the driving charge is fired.

Insomuch as any development from this point will involve the expenditure of considerable money it is pertinent to consider the application of the rocket principle that may justify such expenditure.

The 81 mm T.M. has a range of about 3200 yds. with a 7.43-pound shell carrying 1.13 pounds of T.N.T. and is quite accurate. It also fires a 15.07 pound shell carrying 4.35 pounds of T.N.T. to a range of 1280 yds.

Considering a rocket projectile for the same weapon it is not practicable to build a 7-pound projectile. A 14-pound rocket-projectile has been made which carried 1.6 lbs. of T.N.T. and had a range of 2200 yds. or a 71% increase over the standard 15 lb.

81 mm shell. Assuming that an increase in efficiency of the driving charge and shell can be made to give a range of 3000 yds. or better, it still would offer little advantage over the present weapon because it is quite probable that this range can be reached with a 15 lb. finned shell of improved conventional design fired from the same tube. Add to that the fact that the accuracy of the rocket is unknown, its expense probably would be greater and that the weight of the firing weapon is not reduced, there would be little justification of the expense necessary to develop a rocket-projectile for use with this weapon. Even were it possible to reach a range of 7000-8000 yds. with a rocket shell carrying 3 lbs. of T.N.T., to keep within a weight of 15 lbs., the shell wall would be too thin for effective fragmentation and if the shell wall were made thick enough to give effective fragments the weight of the ammunition would be much increased. In short, such a shell could do little that a 75 mm shell fired from a gun cannot do and in addition it would be limited to plunging fire. It is true that the mortar firing the rocket shell weighs much less than a 75 mm gun, however the mobility of the gun is great and offers no insurmountable difficulty, not enough certainly to warrant the development of a new weapon of this type to take its place.

Now consider the 105 mm howitzer. This weapon fires a 33 lb. shell carrying 4.9 lbs. of T.N.T. to a maximum range of 11600 yds. The total weight of the fuze round (shell, fuze, propelling charge and cartridge case) is about 42 pounds. The howitzer weighs in firing position 3600 pounds.

It is computed that a rocket-shell weighing 39 pounds complete with fuze and propelling charge could be made which would carry a 4-pound driving charge and a 6-pound bursting charge and have walls sufficiently thick for good fragmentation. In order to fire such a projectile at a maximum muzzle velocity of about 800 f/s., the gun for firing it would require a recoil mechanism and would probably weigh little less than the present howitzer although rifling might not be necessary. Assuming equal or greater maximum range can be obtained the advantage of the rocket shell would be in the delivery of about 1 lb. more T.N.T. at the point of burst and saving of about 2 lbs. in total weight per round. This hardly seems enough to warrant the development of a new shell whose characteristics are unknown to replace the present shell. The problem of mobility with the 105 mm howitzer is still not one of great difficulty and a weapon of similar caliber to fire the rocket-shell would offer little advantage from this standpoint.

If however a rocket shell can be made to give equal range with delivery of as much explosive in a shell weighing no more than the present complete 105 mm round, and this can be done with a muzzle velocity of only 300 f/s then the weapon could be much simplified and probably be reduced in weight to about 1800 pounds. This of course would be some advantage. From the standpoint of

use a rocket-shell of this caliber would be of doubtful increased value over the present 105 mm shell. However from the standpoint of development of the principle for application to larger calibers, this size would offer probably the maximum economy for a reasonably favorable volume-weight relation.

The 155 mm howitzer Model 1918 fires a 95 lb. shell carrying 15-19 lbs. of T.N.T. to a range of 12,400 yds. The weapon in firing position weighs 8260 lbs.

It is computed that a finned rocket-shell of the same caliber carrying 20 lbs. of T.N.T. and a driving charge of about 9 lbs. could be made to weigh not more than 80 lbs. If this driving charge can be made to function sufficiently well so that only a 300-400 f.s. muzzle velocity is necessary to give a 12,000 yard range, then a simplified smooth bore gun weighing probably less than half that of the present weapon would meet requirements. Of course it is problematical that the rocket can be made to function this well - if it cannot then it is not worth application; if it can be, then the increased mobility of the weapon and the saving in weight of the ammunition may be worth the effort and money.

There are two ways in which the rocket charge may be used. The first is to give the shell a low muzzle velocity and build it up with the rocket charge to give the desired range. The second is to use a high muzzle velocity and add an increment of velocity to give a super-range by means of the rocket charge.

Attention is here invited to the fact that the rocket-charge is not designed to burn over a long period of time as is the usual idea gained from the conventional sky rocket. The ordinary sky-rocket according to Dr. Goddard is only about 2% efficient, is almost entirely filled with driving charge and carries a very small pay load. The long burning time is due to low exit velocity of the gases which is one of the reasons for the low efficiency. It is apparent that it would be necessary in a projectile to carry a very large driving charge to get a long burning time and still have an exit velocity of the gases of 6000 f/s or better. It has been found in actual firings made in this investigation that it is more effective as well as much more practicable to fire a given charge as fast as possible consistent with keeping comparatively low pressure in the driving chamber (in order to save weight in the latter) than to attempt to stretch the burning time over considerable time. Therefore in practice it is the writer's opinion that charge and orifice should be so designed as to burn the driving charge as rapidly as possible and still keep the pressure not over 3000-4000 lbs./sq.in., and also to do this, where the maximum ordinate of the trajectory is not high enough to reach rarified air, as

near the muzzle of the firing piece as is consistent with the safety of the gun crew. The point to be made is that the exit velocity must be kept high, let the burning time be what it may.

To go back to the two applications of the rocket charge referred to and considering the first. If a low muzzle velocity is used, a comparatively light gun and a thin-walled high-capacity shell could be used but a large driving charge would be necessary to build up the velocity to give a long range. This would materially reduce the space available for the bursting charge and increase the weight of metal in the shell that would play little if any part in the fragmentation and bursting effect (the driving charge chamber). Take as an example our 240 mm Schneider Howitzer. This weapon fires a 245 lb. shell carrying 49 lbs. of T.N.T. to a maximum range of 16390 yds. with a muzzle velocity of 1700 f/s. The lowest muzzle velocity at which this weapon is fired is 615 f/s. Assuming we plan to fire this gun at 700 f/s and by means of a rocket charge in the shell, which charge fires at the muzzle of the gun, to build the velocity up to 1700 f/s in order to get about 16,000 yds. range. The low muzzle velocity permits us to use a shell with a wall thickness of only about  $\frac{3}{8}$ " (steel of 90000 lbs./sq.in. tensile strength), which materially increases the capacity of the shell and cuts down its weight. However in order to add the 1000 f/s necessary to bring the velocity to 1700 f/s, we must carry a driving charge of about 34 lbs. of powder, assuming the exit velocity of the powder when burning is 6000 f/s. The driving charge chamber necessary to carry the 34 lbs. of powder and stand safely a pressure of 4000 lbs./sq.in. should weigh about 65 lbs. and occupy considerable space in the shell which leaves space for carrying of about 45 lbs. of T.N.T. The total weight of this hypothetical projectile would be about 225 lbs. and it would be about 32" long in the body plus a 10" discharge tube. The 65 lb. driving charge chamber is of course so much dead weight to be carried along after the driving charge is burned and though it might be arranged so that it would be thrown off after its usefulness has ceased, this would be of little advantage unless a second driving charge were used. In this application the driving charge should have a net effect of adding about 990 f/s (exit gas velocity 6000 f/s) to the initial 700. The firing piece need be built only to withstand the stresses resulting from firing a 225 lb. shell at 700 f/s instead of a 345 lb. shell at 1700 f/s., yet the range should be about the same. If this can be done a definite advantage results from the saving in weight of both the gun and ammunition. It is quite within the realm of possibility to assume an exit velocity of 6000 f/s, velocities higher than this having been recorded by Dr. Goddard.

Now considering the second application. This shell is to fit the 240 mm Howitzer and is to be designed to stand the stresses of firing at 1700 f/s and to have about the same outside



form and dimensions. This shell unloaded and made of common steel will weigh about 296 lbs. and has a cavity capacity fuze of about 868 cu.in. which must be divided between a bursting charge and a driving charge. A 30 lb. T.N.T. bursting charge will occupy 587 cu.in. leaving 281 cu.in. for the driving charge or 16 lbs. of double-base powder of a density of .057 lbs./cu.in. If we can burn this to give a gas exist velocity of 6000 f/s then we can add about 288 f/s to the 1700 and get 1988 f/s effective muzzle velocity which should give a range of about 19,200 yds. In other words, we have sacrificed 19 lbs. of T.N.T. for an increase in range of 2800 yds.

TABULATION								
Shell	Designed for M.V. of	Total Wt. Shell (#)	Burst Charge Wt. (#)	Drive Charge Wt. (#)	Propelling Ch. to give Stated M.V. (#)	Vel. added by Drive Charge (f/s)	Est. Range Yds.	Final Vel. (f/s)
Std. 240	1700 f/s	345	49.2	None	36.5	None	Known 16400	1700
Rocket 240	1700 f/s	345	30	16#	36.5	288	19200	1988
Rocket 240	700 f/s	225	50	34#	5-6#	990	16000	1690

In the two cases considered, the maximum ordinate will be under 20000 feet where the lessened air density is not of so very great importance in reducing resistance. If we were to consider a long range rocket where a maximum ordinate of well over 23000 feet is reached, at which altitude the air density is less than 1/2 that at the earth's surface, then it probably would be advantageous to delay the firing of the driving charge until this altitude were reached, and to give the projectile sufficient initial velocity to get it up to such an altitude, providing this velocity were not so high that excessively heavy shell walls would be necessary to withstand firing stresses.

The 12" mortar Model 1890-1908 firing a 700 lb. Shell at 1500 f/s at an elevation of 65° reaches an altitude of 19850 feet, at which altitude the air density is about half that of the air at the earth's surface.

Assuming an hypothetical rocket shell designed to weigh about the same and to be fired at about the same muzzle velocity but to be used as a long range demolition projectile rather than an armor piercing one (in order to avoid the necessity of using very heavy shell walls) this shell would be 10" in diameter, 70" long, probably finned. The driving chamber walls would be a minimum of .8" thick (of steel with a tensile strength of 125000 lbs./sq.in.

and the driving chamber would have a capacity of about 161 lbs. of powder. The nose section carrying the bursting charge of 50 lbs. would have a minimum thickness of .375" (of steel with a tensile of 75000 lbs./sq.in.) the whole would weigh about 673 lbs. If we fire this shell at a muzzle velocity of 1500 ft/sec. and can reach an altitude of 18000 ft. at 65° then it would probably be more efficient in action if we fire the driving charge beginning at about 16000 ft. rather than at the muzzle of the gun.

On the basis of the following equation the velocity added by the rocket charge is computed:

$$(M_r + M_c) dV_r = -V_c dM_c \quad \text{or on integrating}$$

$$\frac{V_r}{V_c} = -\log_e (M_r + M_c) + C \quad \text{where}$$

$V_r$  = relative velocity of escape of gases.

$M_r$  = Wt. of rocket without driving charge.

$M_c$  = Wt. of driving charge at any time.

$M_{c_o}$  = Original mass of driving charge.

$V_o$  = Velocity of rocket at time of firing driving charge.

$$C = \log_e (M_r + M_{c_o}) + \frac{V_o}{V_c}$$

$$V = V_c \log_e \left( \frac{M_r + M_{c_o}}{M_r + M_c} \right) + V_o$$

Taking

$$V_c = 6000 \text{ f/s} \quad M_c = 0$$

$$M_r = 513 \text{ lbs.}$$

$$M_{c_o} = 161 \text{ lbs.}$$

Then  $V_r = 1590 \text{ f/s.}$

Taking  $V_c = 8000 \text{ f/s}$  then  $V_r = 2120 \text{ f/s.}$

We see from the above, which is only approximate due to the fact that a rocket charge this large cannot be fired instantaneously or even nearly so with low chamber pressure, that about 1500 f/s could be added to the remaining velocity of the shell at 16000 feet, and considerable of the shell's travel from there on would be in air of reduced density where the rocket is at least equally as efficient as on the surface, and where the air resistance is materially reduced. Of course if the gas exit velocity can be stepped up to 8000 f/s or better without excessive pressure in the driving charge chamber, then the velocity can be considerably increased. For example, by about 2100 f/s if  $V_c = 8000$  f/s.

It must be realized that the data on the behavior of rockets is most meager and that all of the above is approximate at best. However from what is available and from the firings done it is the basis of the writer's opinion that the rocket shell diameter should be of a character of at least 4.0", preferably larger, and that it can be best used for super-range projectiles fired to high altitudes at comparatively low muzzle velocity and at targets that cover considerable area. Demand for ammunition for special long range missions for field guns could probably be made at some sacrifice in bursting charge, yet it would enable these guns on occasion to reach out to super-ranges with a projectile carrying enough explosive to have considerable effect.

#### SUGGESTED PROGRAM FOR DEVELOPMENT

The advance of this project will involve the expenditure of considerable money and effort. There is certain fundamental information that should be secured before actual firings of larger caliber rocket-projectiles should be attempted, which are as follows:

1. The development of a driving charge powder which can be burned in fairly large amounts (up to about 150 lbs.) in a chamber having an orifice and which will not produce a pressure of over 3000-4000 p.s.i. This will involve the design at the same time of an orifice of suitable size to fit each quantity of powder fired, since the rate of burning and pressure are largely dependent on the orifice diameter.

2. The design of a suitable discharge tube and orifice shape (to be done by measuring the reaction produced by given driving charges when the chamber is fitted with different degrees of conical discharge tube and orifice shape).

3. With this information established to apply a driving charge and discharge tube to a 105 mm Howitzer projectile designed to be fired at about 1200 f/s muzzle velocity to find

CROSS SECTION, LONGITUDINAL

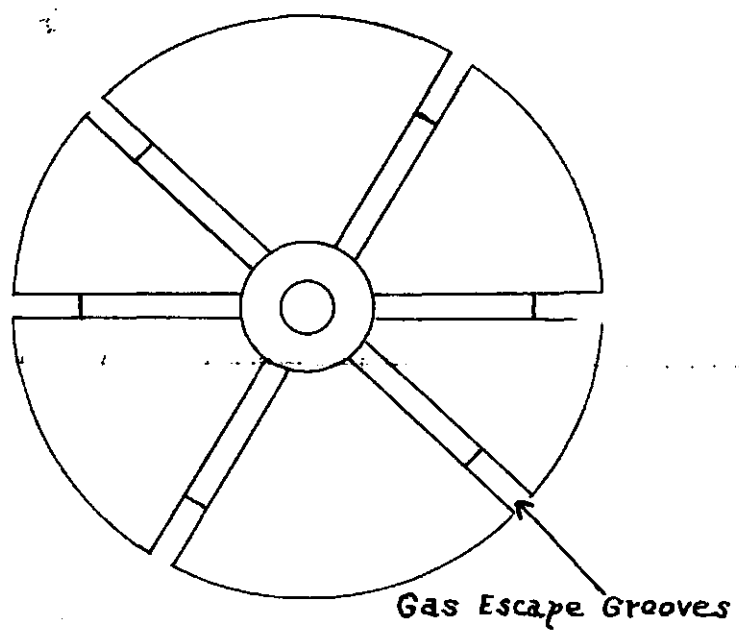
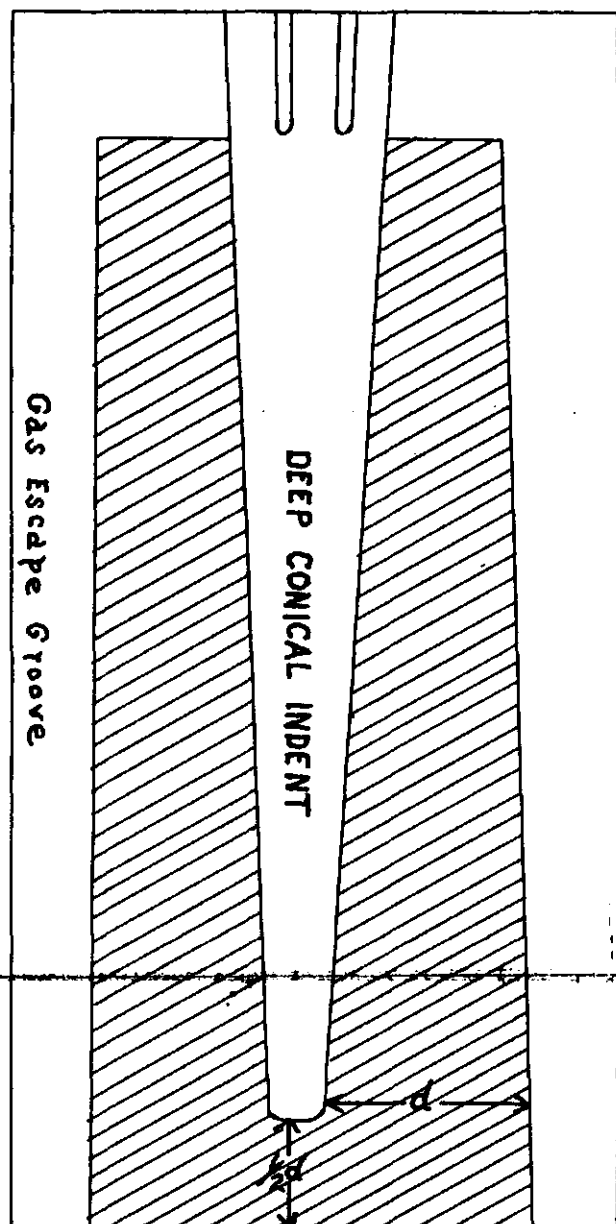


FIG. 6

DRIVING CHARGE WITH GAS ESCAPE GROOVES

out what effect a driving charge will have on a rotating projectile. There is no information available on this subject at present.

4. Make a 105 mm smooth bore tube to fit on the 105 mm Howitzer carriage and fire from it at about 700-1200 f/s a finned rocket shell weighing about 45 lbs. and carrying about 4.5 lbs. of driving charge. While it is not believed that this is a suitable caliber for practical application of the rocket principle for service use it is thought that such firings will give information that will determine the basic design that a larger caliber shell should have and do it with a minimum expenditure of money. There is no information available now on the effect of high velocity (over 1100 f/s) on finned projectiles.

It appears at this time that the driving charge for a projectile of 4" diameter or greater should be a single cylindrical block of powder with a single deep indent in the center and possibly with gas-escape grooves on the sides and top as illustrated in Figure 6. The web thickness of such a block practically necessitates the use of a non-volatile-dispersing-agent-powder and the results obtained in these firings indicate that a double-base powder of 42% or greater nitro-glycerine content has more suitable burning characteristics for this purpose than any other powders in current use. It is not practicable to mount such a block so snugly in a cylinder that burning will take place only on the top surface and on the surface of the deep indent, therefore the charge is designed to permit burning on the outside surface and to provide ready efflux for the gases formed between the walls of the charge and the cylinder walls in order to prevent trapping of the gas and the tendency to break up and force the charge out of the orifice in pieces. The bottom is assumed to be firmly embedded in an adhesive which holds it to the front end of the driving charge chamber.

#### CONCLUSIONS

1. That the ratio of weight to volume in a shell under about 6" diameter is too unfavorable to permit the carrying of a reasonable amount of driving charge without materially reducing the bursting charge.

2. That a rocket shell of about 105 mm would serve as a means of getting data for use in making a more practical shell of larger caliber.

3. That for a powder driving charge we must turn to a non-volatile-dispersing-agent-powder due to the great web thicknesses that will probably be necessary.

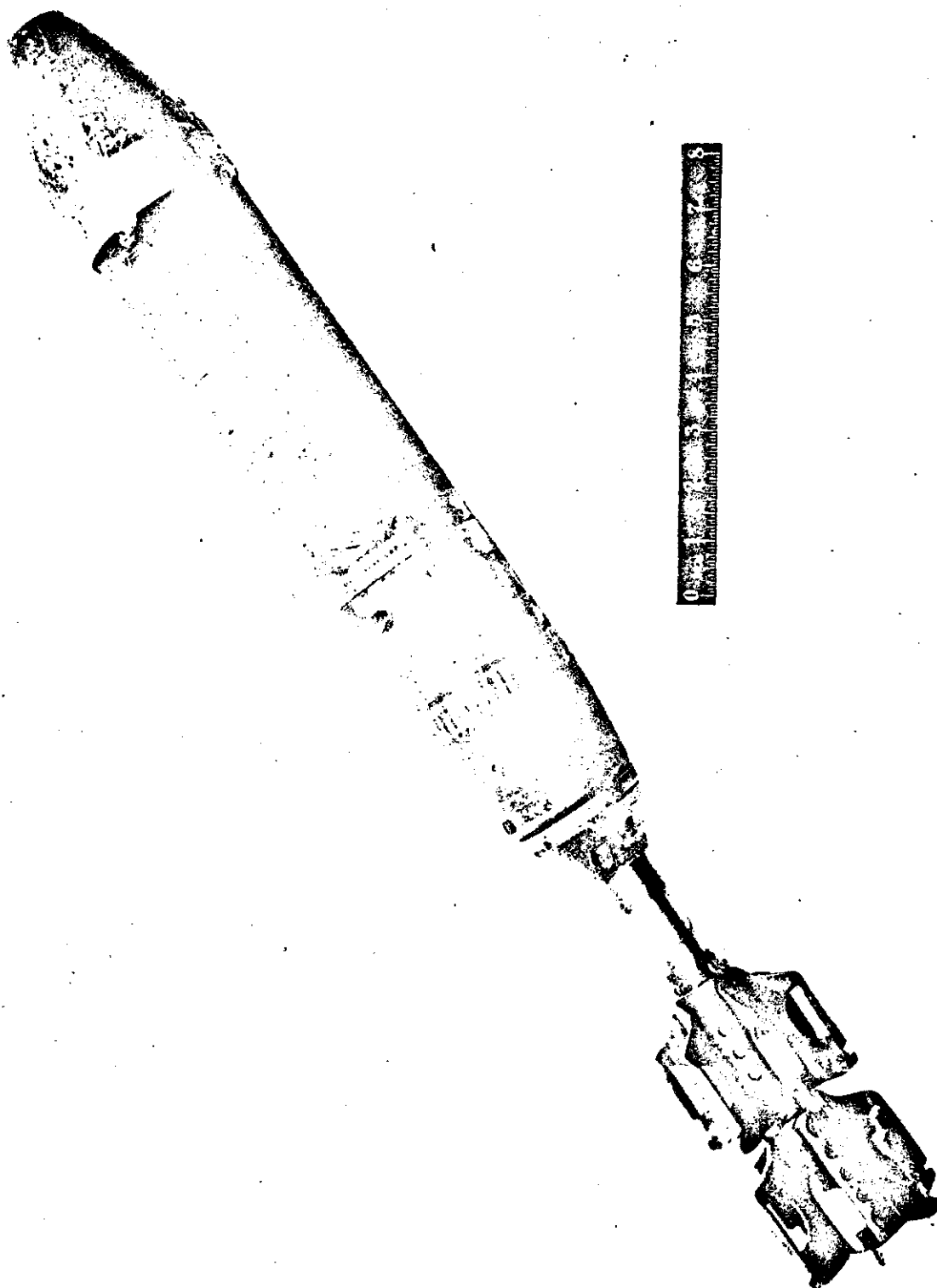
4. That it should be determined whether it is better to apply the driving charge to a rotating or finned shell.

5. That the orifice proper must be of a material more resistant to heat and the erosive action of the gases than steel. Consideration should be given to boron carbide, tantalum and molybdenum as possibilities.

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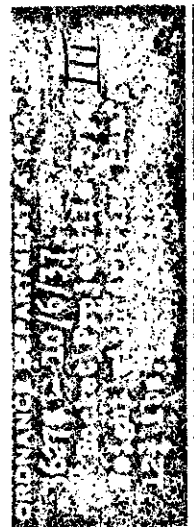
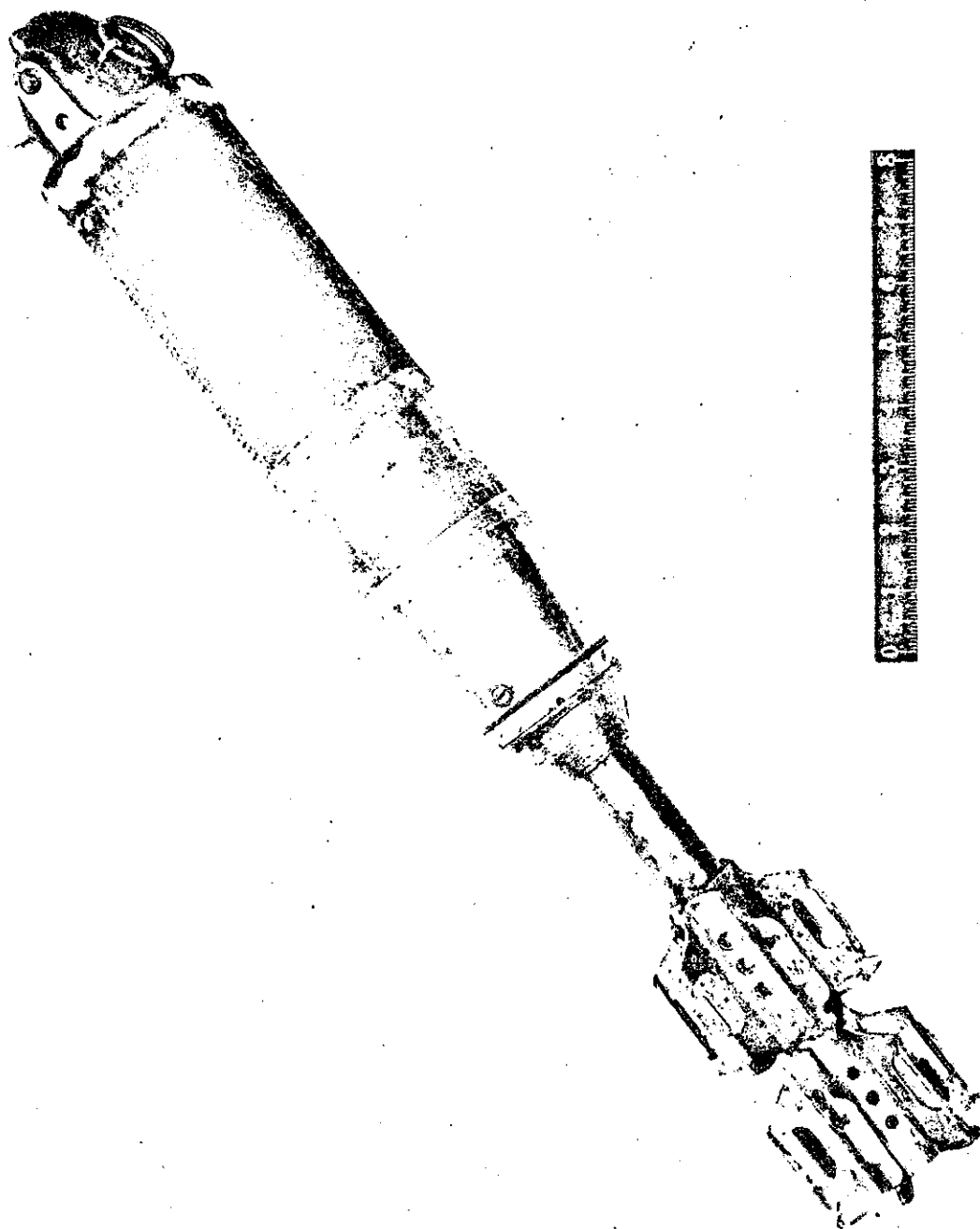




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